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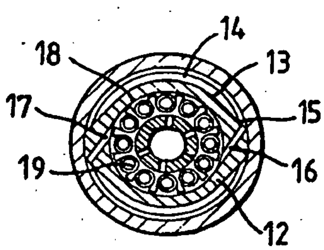

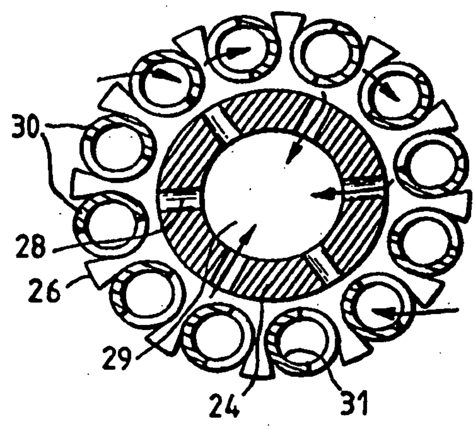

(57) Abstract

A turbine (4) suitable for use in down-hole drilling and the like, and comprising a tubular casing (11) enclosing a chamber (18) having rotatably mounted therein a rotor (19). The rotor (19) comprises at least one turbine wheel (30a) with an annular array of angularly distributed blades (30). The blades (30) are orientated with drive fluid receiving faces (31) thereof facing generally rearwardly of a forward direction of rotation of the rotor (19), and a generally axially extending inner drive fluid passage means (14) generally radially inwardly of said rotor (19). The casing (11) also has generally axially extending outer drive fluid passage means (16), and one of the inner and the outer drive fluid passages (14, 16) are provided with outlet nozzles (17) formed and arranged for directing at least one jet of drive fluid onto the blade drive fluid receiving faces (31) as the blades (30) traverse the nozzle means (17) for imparting rotary drive to said rotor (19). The other of the inner and the outer drive fluid passages (14, 16) is provided with exhaust aperture means (28) for exhausting drive fluid from the turbine (4).

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DRILLING TURBINE

The present invention relates to turbines suitable for down-hole applications such as bore-hole drilling and driving various down-hole tools.

Conventional turbines for down-hole use generally comprises a longitudinally extending turbine stage away in which the drive fluid passes substantially axially through a multiplicity of turbine stages connected in series. Particular disadvantages of this type of arrangement include relatively low efficiency due to the rapid increase of efficiency losses with increasing number of turbine stages, and the considerable length required to achieve any useful torque levels. Typical commercially available turbines of this type having of the order of 100 to 200 turbine stages, have a length of around 20 m and longer. Such a length presents considerable restrictions on the use of such turbines in non-rectilinear drilling e.g. directional drilling situations, because of restrictions on minimum radius of curvature of kick-off which can be used, as well as in drilling operations using coiled tubing because of the large lubricators required to accommodate the turbine together with the drilling tools and other equipment required. This in turn gives rise to substantial practical problems in the positioning of the injector at a suitable height, above the lubricator.

It is an object of the present invention to avoid or minimise one or more of the above disadvantages and/or problems.

It has now been found that a compact, high torque, turbine can be achieved by means of a combined impulse and drag turbine in which increased turbine drive output is obtained by means of increasing the turbine motive fluid energy transfer capacity in parallel rather than in series as with conventional downhole turbines.

The present invention provides a turbine suitable for use in down-hole drilling and the like, and comprising a tubular casing enclosing a chamber having rotatably mounted therein a rotor comprising at least one turbine wheel means with an annular array of angularly distributed blade means orientated with drive fluid receiving face means thereof facing generally rearwardly of a forward direction of rotation of the rotor, and a generally axially extending inner drive fluid passage means disposed more or less radially inwardly of said rotor, said casing having generally axially extending outer drive fluid passage means, one of said inner and outer drive fluid passages being provided with outlet nozzle means formed and arranged for directing at least one jet of drive fluid onto said blade means drive fluid receiving faces as said blade means traverse said nozzle means for imparting rotary drive to said rotor, the other being provide with exhaust aperture means for exhausting drive fluid from the turbine. Preferably the turbine has an plurality, advantageously, a multiplicity, of said turbine wheel means disposed in an array of parallel turbine wheels extending longitudinally along the central rotational axis of the turbine with respective parallel drive fluid supply jets. Instead of, or in addition to providing a said inner or outer drive fluid passage for exhausting of drive fluid from the chamber, there could be provided exhaust apertures in axial end wall means of chamber, though such an arrangement would generally be less preferred due to the difficulties in manufacture and sealing. In yet another variant of the present invention, both the drive fluid supply and exhaust passage means could be provided in the casing (i.e. radially outwardly of the rotor) with drive fluid entering the chamber from the supply passage via nozzle means to impact the turbine blade means and drive them forward, and then exhausting from the chamber via outlet apertures angularly spaced from the nozzle means in a downstream direction, into the exhaust passages.

Thus essentially the turbine of the present invention is of a

radial (as opposed to axial) flow nature with motive fluid being moved between radially (as opposed to axially) spaced apart positions to drive the turbine blade means.

Accordingly with a turbine of the present invention it is possible readily to increase torque by increasing the nozzle output (number and/or extend of nozzles (longitudinally and/or angularly of the turbine) etc) and the blade capacity (number of blades, axial extent thereof (longitudinally of the turbine) etc) so as to increase the parallel flow of motive fluid through the turbine, without suffering the severe losses encountered with conventional multi-stage turbines comprising axially extending turbine wheel arrays of serially connected operating turbine blade sets.

The turbine of the present invention also has some significant advantages over positive displacement motors in that it can use relatively viscous and /or dense drive fluids such as more or less heavily weighted drilling muds e.g. high density drilling muds weighted with bentonite or barytes, which are required, for example, for shallow high pressure wells.

Another important advantage over conventional turbines for down-hole use is that the motors of the present invention are substantially shorter for a given output torque (even when taking into account any gear boxes which may be required for a given practical application). Typically a conventional turbine may have a length of the order of 15 to 20 meters, whilst a comparable turbine of the present invention would have a length of only 2 to 3 meters for a similar output torque.

Yet another advantage that may be mentioned is that the relatively high overall efficiency of turbines of the present invention allows the use of smaller size (diameter) turbines than has previously been possible. With conventional down-hole turbines, the so called "slot losses" which occur due to

drive fluid leakage between the tips of the turbine blades and the casing due to the need for a finite clearance therebetween, become proportionately greater with reduced turbine diameter. In practice this results in a minimum effective diameter for a conventional turbine of the order of around 10 cm. With the increased overall efficiency of the turbines of the present invention it becomes practical significantly to reduce the turbine diameter, possibly as low as 3 cm.

In one, preferred, form of the invention the outer passage means serves to supply the drive fluid to the turbine wheel means via nozzle means, preferably formed and arranged so as to project a drive fluid jet generally tangentially of the turbine wheel means, and the inner passage means serves to exhaust drive fluid from the chamber, with the inner passage means conveniently being formed in a central portion of the rotor. In another form of the invention the inner passage means is used to supply the drive fluid to blade means mounted on a generally annular turbine wheel means. In this case the nozzle means are generally formed and arranged to project a drive fluid jet more or less radially outwardly, and the blade means drive fluid receiving face will tend to be oriented obliquely of a radial direction so as to provide a forward driving force component as the jet impinges upon said face.

In principle there could be used just a single nozzle means. Generally though there is used a plurality of angularly distributed nozzle means e.g. 2, 3 or 4 at 180°, 120° or 90° intervals, respectively. In the preferred form of the invention, the nozzle means are preferably formed and arranged to direct drive fluid substantially tangentially relative to the blade means path, but may instead be inclined to a greater or lesser extent radially inwardly or outwardly of a tangential direction e.g. at an angle from +5° (outwardly) to -20° (inwardly), preferably 0° to -10°, relative to the tangential direction.

As noted above the torque of the motor may be increased by increasing the motive fluid energy transfer capacity of the turbine, in parallel. The driven capacity of the turbine may be increased by inter alia increasing the angular extent of the nozzle means in terms of the size of individual nozzle means around the casing, and/or by increasing the longitudinal extent of the nozzle means in terms of longitudinally extended and/or increased numbers of longitudinally distributed nozzle means. In general though the outlet size of individual nozzle means should be restricted, in generally known manner, so as to provide a relative high speed jet flow. The jet flow velocity is generally around twice the linear velocity of the turbine (at the fluid jet flow receiving blade portion) (see for example standard text books such as "Fundamentals of Fluid Mechanics" by Bruce R Munson et al published by John Wiley & Sons Inc). Typically, with a 3.125 inch (8 cm) diameter turbine of the invention there would be used a nozzle diameter of the order of from 0.1 to 0.35 inches (0.25 to 0.89 cm).

The size of the blade means including in particular the longitudinal extent of individual blade means and/or the number of longitudinally distributed blade means, will generally be matched to that of the nozzle means. Preferably the blade means and support therefor are formed and arranged so that the unsupported length of blade means between axially successive supports is minimised whereby the possibility of deformation of the blade means by the drive fluid jetting there onto is minimised, and in order that the thickness of the blade means walls may be minimised. The number of angularly distributed individual blade means may also be varied, though the main effect of an increased number is in relation to smoothing the driving force provided by the turbine. Preferably there is used a multiplicity of more or less closely spaced angularly distributed blade means, conveniently at least 6 or 8, advantageously at least 9 or 12 angularly distributed blade means.

It will also be appreciated that various forms of blade means may be used. Thus there may be used more or less planar blade means. Preferably though there is used a blade means having a concave drive fluid receiving face, such a blade means being conveniently referred to hereinafter as a bucket means. The bucket means may have various forms of profile, and may have open sides (at each longitudinal end thereof). Conveniently the buckets are of generally part cylindrical channel section profile (which may be formed from cylindrical tubing section).

Various forms of blade support means may be used in accordance with the present invention. Thus, for example, the support means may be in the form of a generally annular structure with longitudinally spaced apart portions between which the blade means extend. Alternatively there may be used a central support member, conveniently in the form of a tube providing the inner drive fluid passage means, with exhaust apertures therein through which used drive fluid from the chamber is exhausted, the central support member having radially outwardly projecting and axially spaced apart flanges or fingers across which the blade means are supported. Alternatively the blade means may have root portions connected directly to the central support member.

The turbines of the present invention may typically have normal running speeds of the order of 3,000 to 10,000, for example, from 5,000 to 8,000, rpm. In order to increase torque they are preferably used with gear box means. In general there may be used gear box means providing at least 5:1, preferably at least 10:1, speed reduction. Conveniently there is used a serially interconnected array of epicyclic gear boxes each having a gearing ratio of the order of 3:1 to 4:1, for example 2 gear boxes each having a ratio of 3:1 would provide an overall ratio of 9:1. Preferably there is used an epicyclic gear box with typically 3 or 4 planet wheels mounted in a rotating cage support used to provide an output drive in

the same sense as the input drive to the sun wheel, usually clockwise, so that the output drive is also clockwise. Preferably there is used a ruggedised gear box means with a substantially sealed boundary lubrication system, advantageously with a pressure equalisation system for minimizing ingress of drilling mud or other material from the borehole into the gear box interior.

In a further aspect the present invention provides a turbine drive system suitable for use in downhole drilling and the like comprising at least one turbine of the invention drivingly connected to at least one reducing gearbox. In yet another aspect the present invention provides a bottom hole assembly comprising at least one turbine of the invention drivingly connected to a tool, preferably via at least one reducing gearbox. In a still further aspect the present invention provides a drilling apparatus comprising a drill string, preferably comprising coiled tubing, and a bottom hole assembly of the invention wherein the tool comprises a drill bit.

Further preferred features and advantages of the invention will appear from the following detailed description given by way of example of some preferred embodiments illustrated with reference to the accompanying drawings in which:
Fig.1 is schematic side elevation of the downhole components of a drilling apparatus with a turbine drive system of the present invention;
Fig.2 is a longitudinal section of part of the downhole drive system of the apparatus of Fig.1 showing one of the turbine power units therein (including Fig.2A which is a transverse section of the turbine unit) but with bearing and seal details omitted for greater clarity); and
Fig.2B is a detail view showing the connection between the upper and lower turbine units;
Fig.3 is a partly sectioned side elevation of the main part of the turbine rotor without the bucket means;

Figs 4 and 5 are transverse sections of the rotor of Fig.3 but with the bucket means in place;
Fig.6 is a transverse section of an epicyclic gear system used in the apparatus of fig.1; and
Fig,7 is a transverse section similar to Fig.2A on an enlarged scale showing an alternative form of turbine configuration.

Fig.1 shows the downhole end of a borehole drilling apparatus drill string comprising a bottom-hole assembly 1 connected to a coiled tubing drilling pipe 2. The principal parts of the assembly 1 are, in order, a top sub 3, an upper turbine 4, a lower turbine 5, an upper gear box 6, a lower gear box 7, a bearing pack 8, a bottom sub 9, and a drill bit 10. As shown in more detail in Fig.2, the upper turbine 4 comprises an outer casing 11 in which is fixedly mounted a stator 12 having a generally lozenge-section outer profile 13 defining with the outer casing 11 two diametrically opposed generally semi-annular drive fluid supply passages 14 therebetween. At the clockwise end 15 of each passage 14 is provided a conduit 16 providing a drive fluid supply nozzle 17 directed generally tangentially of a cylindrical profile chamber 18 defined by the stator 12 inside which is disposed a rotor 19.

The rotor 19 is mounted rotatably via suitable bushings and bearings (not shown) at end portions 20,21 which project outwardly of each end 22,23 of the stator 12. As shown in Figs 3 to 5, the rotor 19 comprises a tubular central member 24 which is closed at the upper end portion 20 and, between the end portions 20,21, has a series of spaced apart radially inwardly slotted 25 flanges 26 in which are fixedly mounted cylindrical tubes 27 (see Figs 4 & 5) extending longitudinally of the rotor. Fig.4 is a transverse section through a flange 26 which supports the base and sides of the tubes 27 thereat. Fig.5 is a transverse section of the rotor 19 between successive flanges 26 and shows a series of angularly spaced exhaust apertures 28 extending radially inwardly through the tubular central member 24 to a central axial drive fluid

exhaust passage 29. Between the flanges 26, the tubes 27 are cut-away to provide angularly spaced apart series of semi-circular channel section buckets 30 forming, in effect, a series of turbine wheels 30a interspersed by supporting flanges 26. The buckets 30 are oriented so that their concave inner drive fluid receiving faces 31 face anti-clockwise and rearwardly of the normal clockwise direction of rotation of the turbine rotor 19 in use of the turbine. The buckets 30 are disposed substantially clear of the central tubular member 24 so that drive fluid received thereby can flow freely out of the buckets 30 and eventually out of the exhaust apertures 28. With the rotor 19 being enclosed by the stator 12 it will be appreciated that in addition to the "impulse" driving force applied to a bucket 30 directly opposite a nozzle 17 by a jet of drive fluid emerging therefrom, other buckets will also receive a "drag" driving force from the rotating flow of drive fluid around the interior of the chamber 18 before it is exhausted via the exhaust apertures 28 and passage 29.

The rotor 19 of the upper turbine 4 is drivingly connected via a hexagonal coupling 32 to the rotor of the lower turbine 5 which is substantially similar to the upper turbine 4 and is in turn drivingly connected via the upper and lower gear boxes 6,7 and suitable couplings 33,34,35 to the bottom sub 9 which has mounted therein a drill bit 10. As shown in Fig.6 the gear boxes 6,7 are of epicyclic type with a driven sun wheel 36, a fixed annulus 37, and 4 planet wheels 38 mounted in a cage 39 which provides an output drive in the same direction as the direction of rotation of the driven sun wheel 36.

In use of the apparatus, the motive fluid enters the top sub 3 and passes down into the semi-annular supply passages 14 of the upper turbine 4 between the outer casing 11 and stator 12 thereof, whence it is jetted via the nozzles 17 into the chamber 18 in which the rotor 19 is mounted so as to impact in the buckets 30 thereof. The motive fluid is exhausted out of the chamber 18 via the exhaust apertures 28 down the central

exhaust passage 29 inside the central rotor member 24 until it reaches the lower end 24a thereof engaged in the hexagonal coupling 32, drivingly connecting it to the closed upper end 24b of the rotor 19 of the lower turbine 5. The fluid then passes radially outwards out of apertures 32a provided in the hexagonal coupling 32 of the lower turbine and then passes along into the semi-annular supply passages 14 of the lower turbine 5 between the outer casing 11 and stator 12 thereof to drive the lower turbine 5 in the same way as the upper turbine 4. It will be appreciated that the lower turbine is effectively driven in series with the upper turbine. This is though quite effective and efficient given the highly efficient "parallel" driving within each of the upper and lower turbines. The drilling mud motive fluid exhausted from the lower turbine then passes along central passages extending through the interior of the gear boxes 6,7, and bottom sub 9 whose upper end extends through the interior of the bearing pack 8, to emerge at the drill bit 10 in the usual way.

With a single turbine unit as shown in the drawings suitable for use in a 3.125 inch (8 cm) diameter bottom hole assembly and a drive fluid supply pressure of 70 kg/cm^2 there may be obtained an output torque of the order of 22.5 m.kg at 6000 rpm. With a 3:1 ratio gearing down there can then be obtained an output torque of the order of 8 m.kg at 2000 rpm. With a system as illustrated there can be obtained an output torque of the order of 2.5 m.kg at 600 rpm which is comparable with the performance of a similarly sized conventional Moineau motor or conventional downhole turbine having a diameter of 4 3/4" (12 cm) and 50 ft (15.24 m) length.

It will be appreciated that various modifications may be made to the abovedescribed embodiments without departing from the scope of the present invention. Thus for example the profiles of the buckets 30 and their orientation, and the configuration and orientation of the nozzles 17, may all be modified so as to improve the efficiency of the turbine.

CLAIMS

1. A turbine (4) suitable for use in down-hole drilling and the like, and comprising a tubular casing (11) enclosing a chamber (18) having rotatably mounted therein a rotor (19) comprising at least one turbine wheel means (30a) with an annular array of angularly distributed blade means (30) orientated with drive fluid receiving face means (31) thereof facing generally rearwardly of a forward direction of rotation of the rotor (19), and a generally axially extending inner drive fluid passage means (29) generally radially inwardly of said rotor (19), said casing (11) having generally axially extending outer drive fluid passage means (14), one of said inner and outer drive fluid passages (29, 14) being provided with outlet nozzle means (17) formed and arranged for directing at least one jet of drive fluid onto said blade means drive fluid receiving faces (31) as said blade means (30) traverse said nozzle means (17) for imparting rotary drive to said rotor (19), the other being provided with exhaust aperture means (28) for exhausting drive fluid from the turbine (4).

2. A turbine (4) as claimed in claim 1 wherein said at least one turbine wheel means (30a) comprises an array of parallel turbine wheels, which array extends longitudinally along the central rotational axis of the turbine (4), and wherein each one of said turbine wheels (30a) has associated therewith a respective said outlet nozzle means (17) for directing at least one jet of drive fluid onto said blade means drive fluid receiving faces (31) of said turbine wheel (4).

3. A turbine (4) as claimed in claim 2 wherein each said turbine wheel (30a) has associated therewith a plurality of angularly distributed nozzles for directing a plurality of jets of drive fluid onto said blade means drive fluid receiving faces (31) of said turbine wheel (30a).

4. A turbine (4) as claimed in any one of claims 1 to 3 wherein each said turbine wheel (30a) has at least 6 turbine blades (30).

5. A turbine (4) as claimed in any one of claims 1 to 4 wherein said turbine blades (30) have a part cylindrical channel section profile.

6. A turbine (4) as claimed in any one of claims 1 to 5 wherein said turbine wheel means (30a) comprises a series of axially spaced apart radially outwardly extending turbine blade support means (26) for mounting of angularly distributed axially extending turbine blade members (30) providing said turbine blades (30) of each said turbine wheel (30a).

7. A turbine (4) as claimed in any one of claims 4 to 6 when dependant on claim 3 wherein said outer drive fluid passage means (14) is provided with said outlet nozzles, and said inner drive fluid passage means (29) is provided with said exhaust apertures (28).

8. A turbine (4) as claimed in any one of claims 4 to 6 when dependant on claim 3 wherein said inner drive fluid passage means is provided with said outlet nozzles, and said outer drive fluid passage means is provided with said exhaust apertures.

9. A turbine (4) as claimed in any one of claims 1 to 8 wherein is provided at least one reducing gearbox (6, 7) and said turbine (4) is drivingly connected to said at least one gearbox (6, 7).

10. A turbine (4) as claimed in claim 9 wherein said at least one gearbox (6, 7) is an epicyclic gear box.

11. A turbine (4) as claimed in claim 10 wherein said at least

one gearbox (6, 7) has a reduction ratio of at least 5 : 1.

12. A turbine (4) as claimed in any one of claims 1 to 10 when drivingly coupled with at least one further said turbine.

13. A turbine (4) suitable for use in down-hole drilling and the like, and comprising a tubular casing (11) enclosing a chamber (18) having rotatably mounted therein a rotor (19) comprising at least one turbine wheel means (30a) with an annular array of angularly distributed blade means (30) orientated with drive fluid receiving face means (31) thereof facing generally rearwardly of a forward direction of rotation of the rotor (19), and a generally axially extending drive fluid supply passage means disposed in a location selected from: radially inwardly of said rotor (19), and within said casing (11), and provided with outlet nozzle means (17) formed and arranged for directing at least one jet of drive fluid onto said blade means drive fluid receiving faces (31) as said blade means (30) traverse said nozzle (17) means for imparting rotary drive to said rotor (19), and said chamber (18) having axial end wall means (29) provided with exhaust aperture means (28) for exhausting drive fluid from the turbine (4).

14. A turbine (4) suitable for use in down-hole drilling and the like, and comprising a tubular casing (11) enclosing a chamber (18) having rotatably mounted therein a rotor (19) comprising at least one turbine wheel means (30a) with an annular array of angularly distributed blade means (30) orientated with drive fluid receiving face means (31) thereof facing generally rearwardly of a forward direction of rotation of the rotor (19), and a generally axially extending inner drive fluid passage means (14) generally radially inwardly of said rotor (19), said casing (11) having generally axially extending, angularly spaced apart, drive fluid supply and exhaust passage means (16), said drive fluid supply passage means (16) being provided with outlet nozzle means (17) formed and arranged for directing at least one jet of drive

fluid onto said blade means drive fluid receiving faces (31) as said blade means (30) traverse said nozzle means (17) for imparting rotary drive to said rotor (12), and the drive fluid exhaust passage means (29) being provided with exhaust aperture means (28) for exhausting drive fluid from the turbine (4).

15. A bottom hole assembly (1) comprising at least one turbine (4) according to any one of claims 1 to 14, which turbine (4) is drivingly connected to a tool (10).

16. A bottom hole assembly (1) according to claim 15, wherein said turbine (4) is drivingly connected to said tool (10) via at least one reducing gearbox (6, 7).

17. A drilling apparatus comprising a drill string (2), and a bottom hole assembly (1) according to claim 15 wherein the tool (10) comprises a drill bit.

18. A drilling apparatus according to claim 17, wherein said drill string (2) comprises coiled tubing.

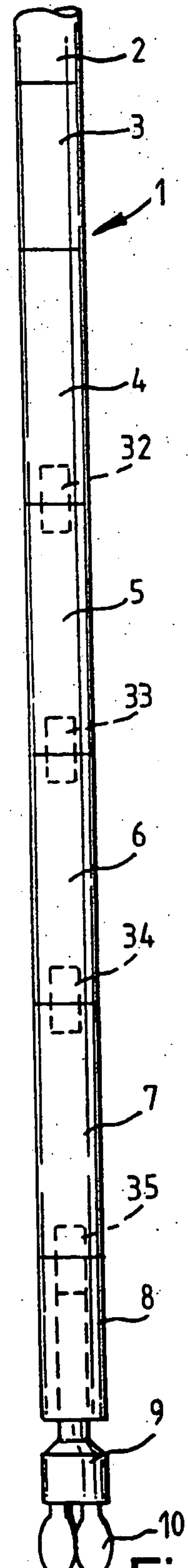

Fig. 1

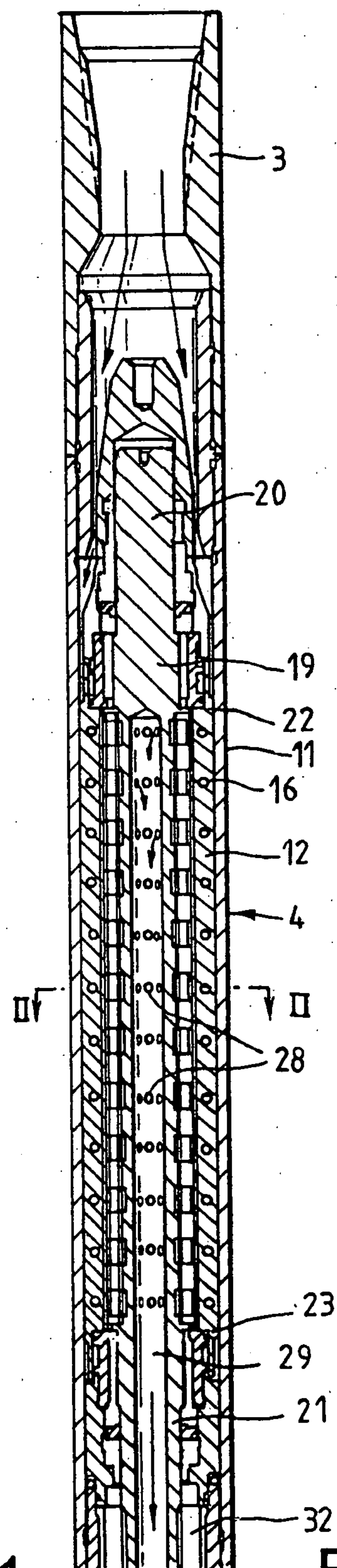

Fig. 2

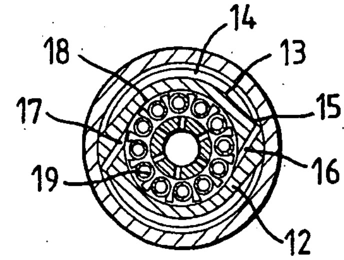

Fig. 2A

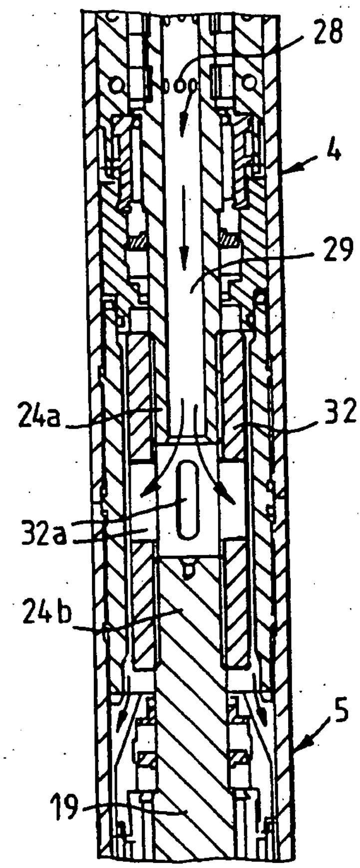

Fig. 2B

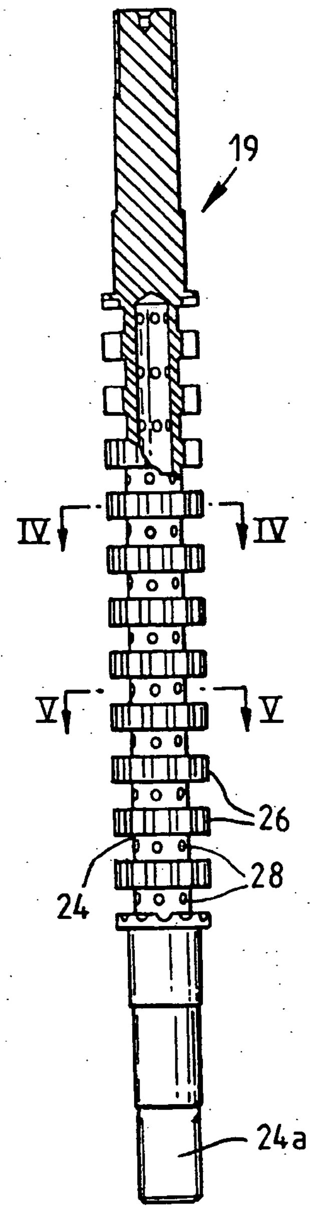

Fig. 3

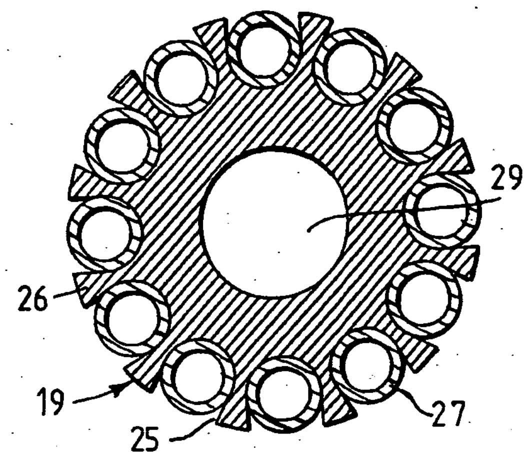

Fig. 4

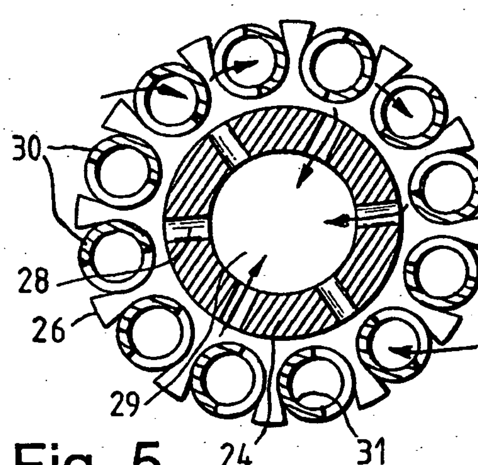

Fig. 5

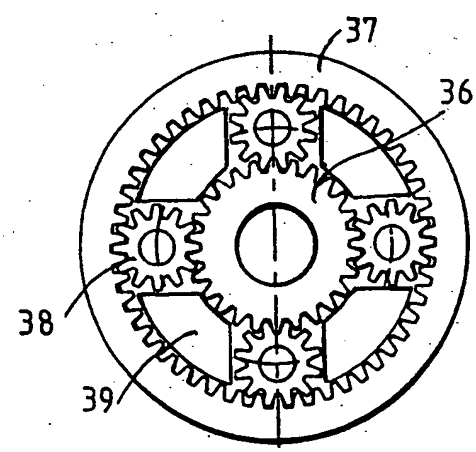

Fig. 6

INTERNATIONAL SEARCH REPORT

International Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 E21B4/02 F03B13/02 F01D1/34

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 E21B F03B F01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 494 401 A (VARADAN) 27 February 1996 (1996-02-27) column 7, line 22 - line 34 -----	1,13-15, 17

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 November 1999	01/12/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Rampelmann, K

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
. T/GB 99/02450

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5494401 A	27-02-1996	NONE	